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RESOURCE ANALYSIS AND LONG-RANGE PLANNING

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The RAND Corporation
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PREFACE

This Memorandum presents the text of a briefing prepared by the author for presentation to the Air Force in May 1963. It is being given wider distribution at this time because of the current interest among military planners in the concepts discussed -- program budgeting, cost-effectiveness, and cost analysis.

SUMMARY

Program budgeting, cost effectiveness, and cost analysis are terms used with increasing frequency in our military establishment. This Memorandum discusses each of the terms, with emphasis on cost analysis, and shows how the concepts that they represent are important for Air Force long-range planning. Since this Memorandum is intended primarily for persons who must provide inputs to, as well as use the results of, cost analyses, examples are given of the kind of detailed information required.

RESOURCE ANALYSIS AND LONG-RANGE PLANNING

Program budgeting, cost effectiveness and cost analysis are three terms used repeatedly in descriptions of new Air Force research programs. Since these are concepts that have only recently become current in the Air Force, it seemed to me that perhaps the most useful thing I could do in this discussion would be to illuminate each of these terms so that hopefully we will all be talking in a common language during the course of future studies.

The fundamental feature of program budgeting is that it aligns or arrays the work statement in terms of the final objective as opposed to the functional or input requirements for accomplishing the objective. Thus, instead of the traditional budget programs such as procurement, military construction and military personnel, resource requirements are presented in terms of weapon systems or, at a higher level of aggregation, in terms of a total mission -- strategic retaliatory forces, defense forces, general purpose forces and the like.

The fundamental purpose of program budgeting in the Department of Defense is to provide the Secretary of Defense and his advisors with a better basis for making program decisions. By major program decisions I mean those pertaining to important choices with regard to alternative weapon or support systems, force structures and their principal modes of employment and deployment. In broad problems the most feasible solutions are often mixes of different systems and forces. It has become increasingly apparent that the selection of the most desirable mix should realistically involve cost as a major element. Mr. Hitch has explained the importance of cost in these words:*

> Furthermore, there has long been a tendency in the Defense Department to state military requirements in absolute terms without reference to their

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*Testimony in <u>Systems Development and Management (Part 2)</u>, Hearings before a Subcommittee of the Committee on Government Operations, House of Representatives, 87th Congress, 2d Session, U. S. Government Printing Office, Washington, 1962, p. 515.

> costs. But the military effectiveness or military worth of any given weapon system cannot logically be considered in isolation. It must be considered in relation to its cost - and in a world in which resources are limited, to the alternative uses to which the resources can be put. Military requirements are meaningful only in terms of benefits to be gained in relation to their cost. Thus, resource costs and military worth have to be scrutinized together.

The relevance of program budgeting to long-range planning is in my opinion threefold. First, it implies an orderly process of planning and programming. In planning, one seeks a continual review of objectives and the means for their attainment. The preferred alternative remains preferred only as long as additional knowledge of program prospects in relation to competitive systems continues to support that choice. The concern is with weighing and evaluating and applying all of one's knowledge in the process. In the cost-effectiveness analyses used in planning, detailed cost estimates, which are characteristic of operating budgets, are not required. In programming, attention is concentrated on translating preferred alternatives into forces, manpower, and dollar costs, and these are projected over a five-year period. More reasonable costing is now in order since one must be able to anticipate the budgetary consequence of approved programs.

It is important to note the difference between programming as frequently performed in the Air Force and programming as I am using the term. In the former, cost may not be taken into account at all -- a program can remain essentially a schedule of the physical activities required to accomplish a certain objective or plan. This kind of programming, however, often results in a mismatch between program and budget. Under the program budgeting concept the translation into dollars must be made up with the schedule, for a program decision is a budget decision and a budget decision is a program decision. Obviously, good cost estimates permit a more effective program budgeting decision.

The second implication that program budgeting as practiced in the Office of the Secretary of Defense has for long-range planning is that in projecting force structures out into the 1970's, the Air Force cannot ignore certain Army and Navy capabilities. Planning in terms of missions rather than standard appropriation categories tends to diminish the relevance of military service boundaries to the major programs such as continental defense or limited warfare. Today, a major program is no longer the exclusive province of an individual military service but rather, in varying degrees, is the province of all the services. Decisions pertaining to the force size of weapon systems where these systems are complementary and not in the same military department -- Minuteman and Polaris, for example -- must be viewed in the context of the total strategic picture. The additional considerations in doing force structure planning in this broader context will certainly complicate our job, but the results should be more realistic and of more real benefit to the Air Force.

Finally, since the Department of Defense and the Air Force now do their planning in program budget terms, it will also be the responsibility of the resource analysts in future studies to package each proposal in program terms for final consideration by the decision-makers. In this we will have to indicate clearly the objective sought, the time dimensions and the commitments required. Basic and applied research and facilities for these activities are one kind of commitment. Advance development or technical feasibility is quite different. Developing, producing, deploying and operating a system are orders of magnitude different from either advanced development or basic research.

When recommending new systems we must talk in terms of total system costs and make it clear whether the capability sought is new or is one which offers some degree of improvement in jobs done by existing equipments. Particularly for the second class of cases we should indicate the extent of the resource commitment at each stage of action; for example, development, production, deployment and employment. If we fully explore technical and operational alternatives, then translate these into complete statements of

step-by step resource and time commitments, much time and effort can be saved at each level of decision-making.

Cost effectiveness, the second term I wish to discuss, is today a rather widely used phrase and, it is my guess, is probably as little understood by most people as any new bit of language. As explained by Mr. Hitch in the testimony referred to above, in cost-effectiveness studies it is necessary to:

(a) Define objectives;

(b) Lay out alternative ways of accomplishing the objective;

(c) Calculate how effectively each alternative accomplishes the objective; and

(d) Calculate how much each alternative costs.

In making the cost-effectiveness calculation it is commonplace to want to minimize cost and maximize effectiveness. Obviously, this is impossible. We can specify effectiveness and then price out the resource requirement to attain that level of effectiveness. Or, conversely, we can introduce a resource or budget limitation and then determine the extent to which we can obtain specified levels of effectiveness for these resource levels. We are not interested here in military requirements studies in the traditional military sense or cost studies in the traditional budget sense. Rather we want military-economic studies that compare alternative ways of accomplishing national security objectives and ones that try to determine the means for accomplishing the most for a given cost or achieving a given objective at least cost.

A typical example of such a study would be one in which the objective is to neutralize a given set of targets. The effectiveness analyst has by far the most difficult part of the job. He must determine the size of the weapons to be used, the number to be delivered on target, the force in-being required to ensure the delivery of the weapons, the measures to be taken to ensure the survival of a sufficient part of the force, and so on. He is forced to deal in kill probabilities, reaction times, reliability numbers, CEP's and a host of similar considerations which when piled up one upon another

tend to demonstrate an aggregate uncertainty that makes cost analysts feel that their estimates are relatively solid.

At RAND it is the system designers, systems analysts and war gamers who deal with the effectiveness calculation. The cost analysts make the resource translations. It is important in undertaking new studies that we all recognize this division of labor in cost and effectiveness work and, particularly, that in our analytical efforts we again realize that one set of analyses relates to the jobs to be done and another to the appropriate resource translations. The cost analyst does not define the development program, the systems, or the forces; rather he takes given descriptions and costs them out. In this respect it is important to remember that the cost analyst can only price what is described to him -- the system, good or bad, will always be the responsibility of the engineers, scientists, and system analysts.

I say this fully aware that in the real world it seldom works out that way. There is a great deal of interaction between the two groups in which cost analysts attempt to obtain the detailed information needed for costing purposes. When the system designers are unable to provide the required data, the cost analysts are forced to draw upon their experience in pricing out analogous systems. While this may be expedient, it is not always desirable. I should like to discourse briefly, therefore, on what cost analysis should involve and what kinds of information cost analysts will expect from capability analysts in order to come up with weapon system and total force cost estimates.

In comparing the costs of military systems we prefer to speak of "cost analysis" rather than "cost estimation" because the analytical breakdown of many complex interrelated activities and equipments is so important a part of the method. Total weapon system cost is viewed as the aggregate of a number of separate functional activities -- installations, personnel, major equipment, associated equipment and the like. By arraying the cost of each activity for a variety of alternative system configurations the planner can get an appreciation of the trade-offs available to him as well as the possible range of system cost.

Help in choosing among alternative systems is not the only area in which weapon systems cost analysis can be useful. Other uses may involve choices among alternative courses of action in an R&D program, or after a system is phased into the operational inventory, choices among possible hardware modification programs. As an example of one of the applications of cost analysis that may be useful in this connection, consider a study in which we participated several years ago. The problem was to determine the size of the crew compartment in a nuclear powered aircraft. There were three 'givens' in this problem: (1) a crew size of five men, (2) each aircraft had to be capable of remaining in the air continuously for five days, and (3) the total force had to be capable of maintaining one million pounds of payload aloft continuously. The volume of the crew compartment had been tentatively established at 500 cubic feet after looking at various tradeoffs between payload, aircraft gross weight and the weight of shielding required to protect the crew from nuclear radiation.

It is obvious that as the volume of the crew compartment is increased, the requirements for shielding increase and with them the gross weight of the aircraft. If gross weight is held constant when the weight of the crew compartment increases, payload weight decreases and more aircraft will be required to complete the system's mission. More mission aircraft require more flight crews, more maintenance facilities, more personnel, etc. The question was one of obtaining some quantitative measure of what happened to the cost of the entire weapon system when the crew compartment size was varied from the 500 cubic feet. It was only by placing the problem in a total system environment that the effect on system cost of variations in a key specification could be observed. A decision made simply on the basis of how much it would cost in terms of a single item of hardware, thereby neglecting all of the interdependent cost factors in other parts of the system, could have been greatly in error.

As I mentioned a few minutes ago, a cost estimate is tied to a description furnished by someone other than a cost analyst. It is axiomatic that the estimate cannot be better than the statement of requirements on which it is based; yet these statements as they

reach us sometimes reflect their creator's own particular interest and very little else. An airframe designer may provide speed, range, altitude, and weight data, but nothing on electronics, and electronics may represent as much as 50 per cent of the cost of the total aircraft. An advocate of solid propellant rockets for some task may have only the vaguest idea of the type of thrust vector control that will be employed, or whether the casing will be made of steel, fiberglass or titanium. Yet this is the kind of information we must have.

To illustrate this point further, I should like to show you examples of some of the worksheets we now use to accumulate the information needed to estimate research and development costs. Chart 1 shows the desired inputs and cost elements needed to estimate costs of developing liquid propellant airframes. Note that all the blanks above the dashed line must be filled in by what in some cases would be termed a capability analyst. Chart 2 shows the same for propulsion systems. The kinds of inputs required to prepare a cost estimate naturally vary with the type of subsystem for which the estimate is being made. The design parameters and characteristics listed on our worksheets arise from our estimating equations. In addition to these inputs the worksheets call for major milestones and major assumptions. Schedule information is necessary for the task of distributing dollar estimates over time. The major assumptions must be spelled out to make clear exactly what the costs stand for. Also this allows one to revise basic assumptions, hence, estimates, as more becomes known about the development problems encountered.

Following the cost estimates prepared for each individual subsystem the costs of testing and evaluating the complete system are estimated. Chart 3 was designed to aid in this task, and it shows the various inputs desired and the cost elements employed in estimating the System Test category. The final chart (No. 4) is used to summarize estimates for the individual subsystem Design and Development costs and the System Test estimate. Further, this last chart adds a final cost category, System Management and Technical Direction.

Most of these inputs are relatively straightforward; yet they assume we know what in fact we often really do not know -- the length

of a development program, for example, and the amount of test-to-failure hardware, the number of flight tests and the number of engineering hours that will be required. We don't really know sometimes whether the system desired can be developed at all -- I am sure all of us can think of examples where hundreds of millions of dollars have been spent and the design specifications never achieved.

Minimum development time and minimum cost are both worthwhile objectives although mutually incompatible. The nation which is first in the field with an important new weapon may gain a decisive military advantage, while a weapon system which is too late will be unable to cope effectively with the newest enemy threats. These considerations, while important, are intangibles, and it is seldom possible to predict in advance when a difference of a year or two will be significant. Minimum cost, on the other hand, is a concept appreciated by almost everyone. Many costs reflect the scarcity of real resources and especially of talented engineers and scientists, competent managers and skilled production workers. The uneconomic use of resources in one weapon program deprives other military programs of resources they may require, or it prevents the advance of non-defense wants such as education, roads, housing, aid of underdeveloped nations, etc. We must therefore view any weapons proposal as operating within a resource constraint since the amount of resources available for weapons is never unlimited, either in time of peace or war.

One must then be convinced not only of the need and technical feasibility of a new program; one must be certain that the program is feasible in the way it is proposed. In other words, the Air Force may decide that a variable geometry wing is desirable and feasible, but before embarking on a development program it must have confidence in a particular design, not a general concept. Presumably, this is what a program definition phase will supply, and this will be reflected in estimates of weapon system R&D costs.

What of the non-weapon system development areas, however? The organization of a variety of technical panels within recent projects would seem to imply a field of interest other than force structure and individual weapon system analysis, i.e., an appraisal of applied

research and advanced development programs in each of these prospective areas. These appraisals would probably comment on current levels of Air Force effort in each prospective area, the adequacy of coverage, the reality of current goals, etc. Presumably, these investigations would terminate in suggestions for future efforts in each prospective area. If the technical panels were to go even further and lay out prospective R&D programs, it would not be unreasonable to expect the cost analysts to be asked to translate these programs into dollars. While it might be argued that significant cost distinctions between alternative programs of this kind are almost impossible and possibly dangerous, the general levels of resources required could be quite useful.

We at RAND have, perhaps, a peculiar responsibility for studying the financial implications of these non-weapon system R&D areas, because over the years we have recommended again and again on proposed weapon systems suggesting that system development activities be postponed pending more applied research in the major problem areas. We have rarely gone further, however, and suggested the level of funding that would be required to complete the necessary research. Hence, almost all of the main tasks involved in developing a costing capability in non-weapon system R&D remain to be accomplished.

In view of our present workload, this would hardly seem an appropriate time for the new major effort this could involve. On the other hand, the capability analysts on new studies will undoubtedly be accumulating information on the time, equipment, facilities, and manpower required for various research programs. This information the cost analysts could translate into cost without undue effort.

Up to now I have spoken only of the inputs a cost analyst requires for estimating R&D costs. Two very important areas remain -- initial investment and annual operating costs. Since many of you may be familiar with the cost categories involved, I am not going to dwell upon them in detail. I have had charts 5 through 10 prepared to illustrate the kinds of information needed before a total weapon system cost estimate can be completed. The ballistic missile described is purely hypothetical, and under no circumstances should it be regarded as a new RAND-proposed weapon system.

One final comment. The detail shown here may give an impression of exactitude, and no one is more aware of the inexactness of cost predictions than we in the business. Cost estimates can differ from the actual for any number of reasons -- design changes, unforeseen difficulties, omissions in the initial requirements, changes in the operational concept, program stretch-outs, or poor cost estimates. The important thing is not, however, that this uncertainty exists -- it is that we be constantly aware of its existence in doing advanced planning and take it into account. One procedure for doing this has come to be known as cost sensitivity analysis. Briefly, this is a systematic examination of how total system cost changes as key system characteristics are varied over a relevant range. In an R&D program, for example, the cost may be highly sensitive to the number of flight test vehicles. Since, admittedly, one cannot predict the exact number of flight tests required to prove out a new vehicle, it would appear prudent to look at a range of numbers to see what the possible range of costs is. Similarly, if the reliability of a piece of equipment in terms of mean time to failure has a significant effect on system cost, it is well to know what happens to cost if the reliability specifications are not met.

This brings us to what I think can be the major contribution of cost analysis to long-range planning -- that is, the development of sensitivity analyses which will treat of the projections of technology into future systems and force structures. The proposals for new activities will involve a wide range of uncertainties. By analyzing each of these in terms of major component activities it should be possible for the resource analysts to indicate to the designers the elements which are most significant in a resource sense. Then, by having the engineers introduce alternative ways for accomplishing the objective, the resource analyst can work with the engineers to determine the way in which the job can best be done in cost terms.

Worksheet No. 1

AIRFRAME SUBSYSTEM DESIGN AND DEVELOPMENT COST ESTIMATE

Project__________ Date__________

Stage Designation__________ Vehicle Designation__________

Design Parameters and Characteristics

Type of Material__________ Airframe Length__________ft

Type of Construction__________ Airframe Diameter__________ft

Propellant Combination__________ Density__________ lb/ft^3

Propellant Weight, W_p __________lb Volume__________ ft^3

Airframe Weight, W_a __________lb Ratio, W_a/W_p __________

Propulsion System Designation__________ Manufacturer__________

Number of Engines per Propulsion System_____ Thrust per Engine__________lb

Other: __________

Major Milestones

Program Approval__________ Contract Award__________ Prel Design Complete__________

First Test, Battleship__________ Static__________ Flight__________

Other: __________

Major Assumptions__________

____

____

Design and Development Costs		(Millions of Dollars)
Preliminary Research and Design Studies		__________
Development Engineering and Hardware		__________
Airborne Equipment	__________	
Ground Equipment	__________	
Industrial Facilities		__________
Other (Captive Test)		__________
(Propellant)		__________
Total Design and Development Costs		__________

Chart 1

Worksheet No. 2

ROCKET ENGINE SUBSYSTEM DESIGN AND DEVELOPMENT COST ESTIMATE

Project ____________ Date ______________

Rocket Engine Designation ____

Design Parameters and Characteristics

Nozzle Type ____________________ No. of Thrust Chambers (if Plug) ______________

Propellant Feed System __________ Propellant Combination ______________________

Rated Thrust ________________ lb Engine Weight ______________________________ lb

Other: ____

Major Milestones

Program Approval _______ Contract Award ______ Industrial Facilities Complete ________

Prel. Design Complete ______________ Begin Component Development ______________

Begin Engine System Test ______________________ PFRT Complete ______________

Deliver First Flight Engine ____________ Complete Engine System Test ______________

Other: ____

Major Assumptions ____

____

____

Design and Development Costs		(Millions of Dollars)
Preliminary Research and Design Studies		________
Development Engineering and Hardware		________
Airborne Equipment	________	
Ground Equipment	________	
Development Instrumentation		________
Propellant, etc		________
Industrial Facilities		________
Other (______________)		________
(______________)		________
Total Design and Development Costs		________

Chart 2

Worksheet No. 3

SPACE VEHICLE SYSTEM TEST COST ESTIMATE

Project____________ Date____________

Design Parameters and Characteristics

Stage Designation, First________ Second________ Third________

Propellant Combination, First________ Second________ Third________

No. of Liquid Propellant Engines, First________ Second________ Third________

Total Liquid Propellant Weight________lb Volume________ft^3

Solid Propellant Weight per Motor________lb No. of Motors per Stage________

No. of Segments per Motor________ Motor Diameter________in

Location of Flight Test Site________ No. of Flight Tests________

No. of Captive Test Stages, First________ Second________ Third________

Other________

Major Milestones

Test Facilities Complete, Captive,________ Flight________

First System Test, Captive________ Flight________

Completion of Flight Test Program________

Major Assumptions________

System Test Costs

		(Millions of Dollars)
Vehicle Fabrication		________
Airframe	________	
Propulsion System	________	
Other (________)	________	
(________)	________	
Vehicle Spares		________
Test Operations		________
Test Facilities		________
Test Age		________
Propellants		________
Instrumentation		________
Other (maintenance and supply, data reduction and analysis, handbooks, etc)		________
Total System Test Costs		________

Chart 3

Worksheet No. 4

R&D COST SUMMARY BY VEHICLE

Project ____________ Date ______________

Vehicle Configuration ______________________________

Design Features

	Booster	2nd Stage	3rd Stage
Propulsion System	________	________	________
Thrust, lb	________	________	________
Airframe Diameter, in	________	________	________
Other (__________)	________	________	________
(__________)	________	________	________

Major Milestones

Program Approval ______________________

Limiting Subsystem ______________________ And Its Contract Award ______________

Delivery of First Flight Test Vehicle ______________________________________

Other ____

Major Assumptions ____

____

____

- -

R&D Cost Summary (Millions of Dollars)

I Design and Development ______________

Airframe ______________

Booster ______________

2nd Stage ______________

3rd Stage ______________

Propulsion ______________

Booster ______________

2nd Stage ______________

3rd Stage ______________

II System Test ______________

III System Management and Technical Direction ______________

Grand Total R & D Costs ______________

Chart 4

PME and AGE Descriptive Data

Range	7500 n mi
Payload	1200 lb
Length	75 ft
Gross lift-off weight	100,000 lb
Number of stages	1
Type of propulsion	segmented solid propellant
Thrust	125,000 lb
CEP	0.5 mi
Reaction time	5 min
Salvo capability	100% or staggered fire
Degree of automation	Each silo capable of activating missiles and performing confidence checks automatically at periodic intervals and on command from the LCC.

Chart 5

Installations Data

Silo	Hardened to withstand 300 psi overpressure. Underground structure of reinforced concrete 18-in. thick with laminated plastic and steel inner liner, 20 ft in diameter, 100 ft deep, covered by 120-ton concrete cover.
	Surrounded at lowest level by room 15 ft wide providing space for checkout equipment and minimal housing for maintenance crew.
	Occupies at least 2 acres of ground enclosed by security fence. A second security fence 1500 ft from silo is also required.
Launch control center	Hardened to withstand 1000 psi overpressure.
	Occupies plot of at least 4 acres and provides space for paved parking zone, auxiliary power-generating equipment, support building for site maintenance and temporary housing, and security fencing.

Chart 6

Operational and Organizational Data

Force size	2000 missiles
Activation rate	Buildup to 25 wings by end of FY 67. First squadron operational during FY 63.
Organization	25 missiles per squadron; 3 squadrons per wing. LCC controls all missiles in one squadron, has secondary capability of controlling all missiles in wing.
Support base	One support base per wing to house wing personnel and provide administrative and maintenance facilities. Support base will share or use existing SAC bases where possible.
Deployment	1 missile per silo; 1 LCC per squadron. A minimum of 10 n mi between silos. Each silo located within 0.5 mi of surfaced road capable of withstanding axle loads up to 20,000 lb. All silos located in remote areas of the continental U. S.

Chart 7

<u>Communications</u>	Voice contact via underground cable from any point in squadron to any other point. This network hardened to 1000 psi. A backup radio system at each LCC.
<u>Manning Policy Data</u>	
LCC	Manned around the clock by 4 airmen and 1 officer.
Field maintenance crews	5 technicians working 2 days on continuous duty followed by 2 days off. One crew per 5 missiles.
Backup maintenance crews	One backup crew for every 3 field maintenance crews. 5 technicians per crew, available around the clock.
Support base	Maintenance facility operated on one-shift, 5-day-per-week basis.
<u>In-commission Rate Data</u>	
Half of entire force will be maintained on alert at all times.	

Chart 8

<u>Maintenance Concept Data</u>

Estimated failure rate	500 malfunctions per wing per month: 350 on missiles, 150 on ground check-out equipment.
Periodic inspections	Each missile removed from silo every 15 months and recirculated to maintenance facility at support base. 2000 man hours required per missile. Missile to be absent from silo no more then 10 working days.
Maintenance in silo	Silo serviced by field crew responsible for 5 missiles. Crew moves continuously from one missile to another performing confidence checks.
Support base	Major maintenance and service facility for complete vehicles at support base. This facility capable of removing and replacing failed black boxes. Repair of black boxes takes place in centrally located contractor or service depot.

Chart 9

Training Data	
Direct personnel	Formal ATC training required for all direct personnel. Formal courses conducted by ATC at its own facilities and by means of mobile training units at wing support bases.
Other personnel	Available fully trained or brought up to required skill level through on-the-job training.
Training missile	Each squadron launches one missile per year for training purposes.

Chart 10

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